

# REPORT DOCUMENTATION PAGE

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**FINAL TECHNICAL REPORT**  
(Period of November 1, 1992 - October 31, 1995)

**including**

**ANNUAL TECHNICAL REPORT**  
(Period of November 1, 1994 - October 31, 1995)

Submitted to  
Air Force Office of Scientific Research  
Building 410, Bolling AFB, DC 20332

by

Ervin Y. Rodin, P.I.  
Professor and Director

Center for Optimization and Semantic Control  
Department of Systems Science and Mathematics  
Campus Box 1040, Washington University  
One Brookings Drive  
St. Louis, MO 63130-4899

in connection with

Grant AFOSR F 49620-93-1-0012:

**ARTIFICIAL INTELLIGENCE METHODOLOGIES IN  
AIR TRANSPORTATION NETWORK ROUTING AND SCHEDULING**

January 31, 1996

## TECHNICAL REPORT

This is the third annual technical report and also the final report for grant AFOSR-F 49620-93-1-0012. While its principal technical portion consists of two voluminous attachments to this report (182 and 208 pages respectively), which are the principal results of this past third year of the grant, it may be appropriate to summarize first the achievements of the first two years, followed by a longer description of the developments during year 3. We begin by listing the individuals participating in, and/or being supported by this grant during its three years.

### Personnel

The administrative framework at Washington University, under the auspices of which this research was conducted, is the Center for Optimization and Semantic Control. The personnel involved during the three years here reported were as follows:

**Faculty:** Rodin, E.Y., Director (Optimization, O.R., A.I.)

Mukai, H. (Optimization)

Louie, R. (Decision Theory)

Amin, M. (Neural Networks)

Clark, R. (Neural Networks)

Byrnes, C. (Nonlinear Control)

Isidori, A. (Nonlinear Control)

Dai, Liyi (Discrete Event Systems)

**Affiliate Faculty:** T. Kowalsky, AMC, Scott AFB

A. Waisanen, AMC, Scott AFB

A. Kassos, USTRANSCOM, Scott AFB

A. Garcia, E&S Corporation

J. Graham, United Van Lines

**Graduate Students:** M. Monical

J. Revetta

M. Meusey

K. Ruland

A. Wu

F. Yang

P. De

L. Pan  
T. Cusick  
K. Rink  
V. Gerhart  
A. Liu

**Undergraduate Students:** In any given year, about 6-10.

### **YEAR 1: 1992-1993**

#### **Collaboration with AMC at Scott AFB**

Over the years we found that close collaboration with AMC personnel at Scott AFB is a very essential ingredient for the kind of research success, which can be speedily transformed into operating prototypes by the USAF. Therefore, we had several smaller and larger meetings with the appropriate personnel from Scott AFB in the course of the year, sometimes at the base and sometimes at Washington University. We now list a few details concerning the nature of this interaction. Details were given in the Annual Report.

**Presentations For Scott AFB Visits;**

**Reciprocal Visits;**

**MASS Software Package;**

**Memorandum of Agreement for Collaborative Work;**

**The Semantic Optimization Of Large Scale Transportation Problems;**

#### **Other Activities**

**Visit and Lecture of Prof. Lotfi Zadeh;**

**Artificial Neural Networks In Engineering Conference;**

**Chicago National Meeting of ORSA/TIMS;**

Results of EPSCOR Research;

Publications and Reports

Artificial Intelligence Methodologies for Aerospace and Other Control Systems;

Neural Networks Approach to Control Systems;

Differential Games with Neural Networks;

Aircraft Control in the Presence of Windshear;

Optimal Control in a Layered Defense System;

Teaching Neural Networks Nuclear Physics;

System Identification with Dynamic Neural Networks;

Control and Disturbance Rejection with a Dynamic Neurocontroller;

Maneuver Prediction in Air Combat Via Artificial Neural Networks;

Adjacency of the 0-1 Knapsack Problem;

On Differential Games With Neural Networks;

Character Recognition: Qualitative Reasoning and Neural Networks;

Collision Avoidance and Low-Observable Navigation in a Dynamic Environment;

An Optimization Algorithm with Probabilistic Estimation;

Collaboration With Industry

ESCO Corporation;

United VanLines;

St. Louis Post Dispatch.

## YEAR 2: 1993-1994

### Collaboration with AMC at Scott AFB

During this second year of the present grant we continued and expanded our activities, which began during the first year or earlier. Our activities during the second year seem to have come to the attention of some of the higher echelons of the USAF. Consequently, much of our report was devoted to an evaluation of our activities by senior USAF personnel, as expressed in their letters to us. In particular, we presented

**Letters from General R.R. Fogleman, Chief of Staff, USAF;**

**Letters from General C.H. Roadman II, Command Surgeon, USAF;**

**Letter from General R.J. Boots, USAF;**

In addition to the letters above, two particular documents also summarized aspects of our interaction with the USAF, and the beginning of a relationship with USTRANSCOM:

**A Point Paper, Prepared for General R.R. Fogleman by his staff; and**

**Perceived Benefits Of, And Some Proposed Methods Towards Increased Transportation Command-University Cooperation.**

### Subjects of Research Activities

**Approximate Reasoning Methodologies For Transportation Modeling;**

**Intelligent Vehicle-Highway Systems;**

**Pursuit-Evasion problems;**

**System Identification/ Disturbance Attenuation With Dynamic Neural Nets;**

**Network Optimization With Time Window Constraint Routing And Scheduling;**

**Semantic Control To Evasive Maneuver Selection For Transport Aircraft;**

**Polyhedral And Heuristic Approaches for Multi-Plane Pickup And Delivery.**

### **YEAR 3: 1994-1995**

As we stated at the outset, this report is both a final 3-year report, and also one specifically about year 3. Therefore, we go into much more detail in this section, than in the previous ones.

### **OVERVIEW**

As stated in previous years' reports, the purpose of this research project was to develop a generic model and methodology for analyzing and optimizing large scale air transportation networks, including both their routing and their scheduling. Our methodology to achieve this aim consists in part by studying several specific examples of current problems of this type, arising in the operations of the Air Mobility Command (AMC) at Scott AFB; and in part by developing further the various paradigms that we had employed successfully in the past in similar contexts. These include the utilization of the classical mathematical methodologies of Linear and Integer Programming, in conjunction with Neural Networks clustering algorithms; rule-based Expert Systems; various decision methodologies, such as the Analytic Hierarchy Process; Voronoi diagrams and Delaunay triangulations (for initialization purposes); time dependent integer programming, using Time Sweeps; and other appropriate tools and techniques. We also found it absolutely necessary and very useful to continue to collaborate even more extensively than in the past with military scientists from Scott AFB.

Finally, we should note that all of the objectives of the original proposal have been met, and the results obtained are currently being extended. In addition, several new initiatives, with various elements of the USAF at Scott AFB (HQ/AMC, USTRANSCOM, Command Surgeon) were undertaken and are also currently being studied.

## Accomplishments

During the past year, we have successfully continued several projects. These contributions during the last twelve months include:

**i) Transportation, Optimization and Scheduling Theory:**

- Large-scale transportation systems, specifically the development of a general model and methodologies for analyzing and optimizing large-scale air transportation networks, including network optimization with time window constrained routing and scheduling for the USAF's Air Mobility Command;
- Intelligent Transportation Systems: vehicle control and routing, traffic flow optimization;
- Decision-aiding, control and optimization modules for the purposes of traffic management. Macro-level (traffic control) as well as micro level (path planning and steering control);

**ii) System Identification and Control:**

- Real-time control of a damaged aircraft and implementation of a real-time Riccati solver for the computation of optimal controller gains.
- Development of a simulator for system identification, disturbance rejection and control via dynamic neural networks;
- On-line systems identification and control of a damaged F-15 aircraft. Dynamic neural networks are utilized for on-line system identification.

**iii) Learning Control for Game Theory:**

- Development of a tactical decision support system for situation assessment, navigation and control of a vehicle engaged in evasive maneuvers against multiple pursuers.

Several students have also been actively involved in the above efforts. In particular, the following theses/projects were completed:

Fan Yang, D.Sc. May, 1995:

Doctoral Dissertation:

**Network Optimization with Time Window Constrained Routing And Scheduling**

(Copy of this dissertation attached)

Kevin Ruland, D.Sc. August, 1995:  
Doctoral Dissertation:  
**Polyhedral Solution To The Pickup And Delivery Problem**  
(Copy of this dissertation attached)

Michael Meusey, D.Sc. May, 1996:  
Doctoral Dissertation:  
**Title To Be Determined**

Volker Gerhart, M.S. December, 1995:  
Master's Project:  
**On-line Systems Identification and Control of a Damaged Aircraft**

Elliot Vermes, B.S. May, 1995:  
Senior Project:  
**A Fuzzy Model Approach to the Optimization of Airlift Movements**

Michelle Osburn, B.S. December, 1994:  
Senior Project:  
**Simulation of Shortest-Path Algorithms for Vehicle Routing**

Jamali Samsuddin, B.S. December, 1994:  
Senior Project:  
**Multiple Knapsack Loading Algorithm for Mobility Analysis Support System**

Travis Cusick, Robert Black, Eugene Day and Lance Finney:  
Summer 1995 Volunteers at Scott AFB:  
**Various Projects at HQ/AMC and USTRANSCOM**

### Publications

"Application of Dynamical Neural Networks to Approximation & Control of Nonlinear Systems," (Amin, Rodin, Wu and Nouri), accepted for publication in *Advances in Computational Mathematics*, (co-editors: H.N. Mhaskar and C.A. Micchelli), 24 pp., 1995

"Optimal Requirements Studies: Modeling and Optimization of Mobility Analysis," (Yang, Rodin and Amin), accepted for publication in the *Journal of Military Operations Research*, 26 pp., 1995

**"A Semantic Control Approach to Intelligent Transportation Systems,"** (Amin, Cusick, et. al.), *Intelligent Vehicles '95*, Detroit, MI, 6 pp., September 25-26, 1995

**"A Semantic Control Approach to Evasive Maneuvering,"** (Meusey, Rodin & Amin), Proceedings of the First World Congress on Intelligent Manufacturing Processes and Systems, San Juan, Puerto Rico, 8 pp., Feb. 13-17, 1995

**"Systems Identification and Disturbance Attenuation via Dynamic Neural Nets,"** (Amin, Rodin, Wu), Proceedings of Neural Nets for Aero Control Symp., NASA Ames Res. Ctr , Moffett Field, CA, 16 pp., 1994

**"Intelligent Transportation Systems: Enabling Technologies,"** (Garcia-Ortiz, Amin and Wootton), *MCM Journal*, Vol. 22, 71 pp., 1995

**"Network, Control, Communication and Computing Technologies for Intelligent Transportation Systems: An Overview,"** (Amin, Garcia-Ortiz and Wootton), *MCM Journal*, Vol. 22, no. 4, 14 pp., 1995

**"Evasion from Multiple Pursuers via Semantic Control Theory,"** (Amin, Rodin, et al.), Proceedings of the Guidance, Navigation, and Control Conference, Vol. 1, pp. 478-493, Paper # 95-3226, American Institute of Aeronautics and Astronautics, Baltimore, MD, Aug. 7-9, 1995

**"Intelligent Transportation Systems: A Global Perspective,"** (Wootton, Garcia-Ortiz and Amin), *Mathematical and Computer Modelling*, Vol. 22, 12 pp., 1995

**"Neurocontrol of an Aircraft: Application to Windshear,"** (Amin, Rodin & Wu), *Mathematical and Computer Modelling* , Elsevier Science Ltd, Vol. 22, No. 1, pp. 63-78, May 1995

#### **Edited Journals:**

*Network, Control, Communications and Computing Technologies in Intelligent Transportation Systems*, (co-editors: Amin, Garcia-Ortiz and Wootton), *Mathematical and Computer Modelling*, Elsevier Science Ltd, Vol. 22, No. 4-7, 454 pp. , August 25, 1995

## Interactions

### **Conferences:**

**"Traffic Management via Semantic Control,"** (Rodin, Amin, Liu, and Rink), Executive Briefing, Advanced Development Center, E&S Corp., St. Louis (June 16, 1995)

**"NETO: Network Optimization with Time Window Constrained Routing and Scheduling,"** (Amin, Rodin and Yang), invited presentation at the Third Air Mobility Modeling Workshop, Air Force Institute of Technology, Wright-Patterson AFB (May 25, 1995)

**"System Identification via Dynamical Neural Networks,"** (Amin, Rodin and Gerhart), invited presentation at the Intelligent Flight Control: Advanced Concept Program, NASA/MDA/TSU/WU, St. Louis (May 23, 1995)

**"The Pickup and Delivery Problem: Faces and Branch-and-Cut Algorithm,"** (Rodin and Ruland), Presented at INFORMS National Meeting, Los Angeles (April 1995)

**"Computational Methods for Learning Control and Optimization,"** (Amin), invited seminar at the Dept. of Mathematics and Computer Science, Univ. of Missouri, St. Louis (April 5, 1995)

**"A Semantic Control Approach to Evasive Maneuvering,"** (Meusey and Rodin), the First World Congress on Intelligent Manufacturing Processes and Systems, San Juan, Puerto Rico, (Feb. 13-17, 1995)

**"The Pickup and Delivery Problem: Algorithmic Experiments,"** (Ruland and Rodin), Presented at INFORMS Gateway Chapter Meeting, St. Louis (December 1994)

### **Consultative and Advisory Functions:**

The following presentations were given at the Scott AFB:

**"Modeling of Airfield Operations via Semantic Control,"** (Rodin, Amin, Dai, Rink and Cusick), *USAF Air Mobility Command*, Scott AFB, Illinois (August 15, 1995)

**"System Modeling and Identification: Formulation of Maximum On Ground (MOG) Capabilities,"** (Amin), *USAF Air Mobility Command*, Scott AFB, Illinois (August 15, 1995)

**"Modeling and Systems Identification for Medical Decision Support,"** (Rodin and Amin), Command Surgeon's Office, US Transportation Command (TRANSCOM), Scott AFB, Illinois (March 23, 1995)

**"Approximate Reasoning Applied to Transportation Modeling, Routing and Scheduling",** (Amin and Rodin), Mobility Modeling and Simulation User's Group, Scott AFB, Illinois (Nov. 16 , 1994)

**"Network Optimization with Time Window Constrained Routing And Scheduling: Applications to MASS",** (Rodin and Fan Yang), Mobility Modeling and Simulation User's Group, Scott AFB, Illinois (Nov. 16 , 1994)

**"Polyhedral Solution To The Pickup And Delivery Problem: Applications To Aeromedical Evacuation",** (Rodin and Ruland), Mobility Modeling and Simulation User's Group, Scott AFB, Illinois (Nov. 16 , 1994)

In the course of the year, several other working sessions (at the rate of about 1-2 per month) were held with **AMC, TRANSCOM and Command Surgeon** personnel (Gen. Fogleman, Gen. Roadman, Gen. Hoffman, Gen. Boots, Gen. Wykle, Gen. Handy, Col. Northrup, Lt. Col. Waisanen, Lt. Col. Weimann, Major Simpson, Capt. Satz, Capt. Steppe, Dr. Kassos, Mr. Whisman, Mr. Thompson, Mr. Blanchette and several others) to discuss various AMC, USTRANSCOM and Command Surgeon problemsThese include optimal military medical service delivery, BRACES and formulation of MOG (maximum-on-ground) and other subjects.

### Technology Transfer

It may be appropriate to point out at this juncture, that while most of our research and development efforts are directed towards problems of the USAF and its various components, occasionally we also provide technical advice and assistance to various industrial concerns. The way that this comes about (at no cost to the USAF or AFOSR) is this: our Air Force related research efforts have engendered a great deal of interest among some of the best of both our undergraduate and graduate students. For instance, two of our doctoral students, who are currently working on USAF related problems, have National Science Foundation fellowships. Thus, there is sufficient time and ability to provide those extra services and help to industry as well.

A few comments about the attached letters of support will clarify the reasons for attaching these letters to the present section.

**From Lt. Col. A. Waisanen:**

We have been collaborating with him, and with HQ AMC, extensively. In his letter he mentions one of my former doctoral students working with them: since then two more have joined that group. They are very obviously transferring the technology developed here to the USAF.

**From Lt. Gen. K.R. Wykle:**

His letter relates to the fact that, under a Collaborative Research Agreement that I concluded with Scott AFB some years ago, I was now able to place 4 of my outstanding undergraduate students as summer volunteers with the US Transportation Command. A separate report about this, as well as evaluation of this program, are being prepared for the AFOSR.

**From J.D. Hirsch, MD:**

Dr. Hirsch is one of those civilian physicians who has agreed to advise us and the USAF on our collaborative medically related research. We have been working together with him and with Command Surgeon personnel, to apply our optimization and neural network technologies to military medicine.

**From Col. J.G. Jernigan:**

Col. Jernigan is confirming in his letter our collaborative status in medically related research, and their initiation of a CRDA. We will be utilizing our current transportation optimization methodologies in medicine and its delivery to military patients.

**From J.M. Urnes:**

Dr. Urnes (of McDonnell Douglas) speaks about some of the assistance we have been providing to them, using mathematical and optimization tools originally developed by us under this AFOSR grant. In particular, a control methodology developed by us (under AFOSR sponsorship, about 4 years ago) is now utilized by them for a self-designing flight controller; and our on-line neural network methodology is also used, to assist in the control of severely damaged aircraft.

**From J.D. Graham:**

Col. (Ret) Graham has currently a high position at United Van Lines. He started working with us while he was still active at Scott AFB. In

his letter, however, he speaks about the utilization of our AF related work in his own current industry. It is a direct utilization of some of our optimal transportation scheduling algorithms.

**From J. Wooton:**

Dr. Wooton is managing several of the optimization projects that we have been assisting his company with. These projects are all based on optimal semantic control theory, developed by us several years ago, under AFOSR sponsorship.

DEPARTMENT OF THE AIR FORCE  
HEADQUARTERS AIR MOBILITY COMMAND (AMC)



16 June 95

AMCSAF (XPYR)  
402 Scott Drive, Unit 3L3  
Scott Air Force Base, Illinois 62225-5035

Dr. Ervin Y. Rodin  
Director, Center for Optimization and Semantic Control  
Washington University  
One Brookings Drive, Campus Box 1040  
St. Louis, Missouri 63130-4899

Dear Dr. Rodin

Please accept my thanks for all you do for our office. It's difficult to quantify the value of our relationship, but I can identify some areas where there's benefit. For example, the value of your students' expertise is inestimable, especially the value of Mr Jim Revetta. Senior DoD decision makers have acknowledged on several occasions Jim's critical role in the Strategic Airlift Force Mix Analysis (SAFMA). He has frequently found solutions to seemingly intractable problems. He is able to do this because of his superb analytical background. According to him, most of his technical capability is a product of the education and training he received from you.

Col Northrup and I appreciate the meeting you hosted at Washington University on December 7th to discuss the future of mobility with local leaders in industrial transportation. We have a much better appreciation for the problems and complexity of intermodal transportation. We also appreciate the perspectives of these leaders regarding the practicality of proposed solutions. We're all looking forward to more of these interchanges and other technical meetings.

Finally, I am honored you asked me to participate at Fan Yang's doctoral defense "Network Optimization with Time Window Constrained Routing and Scheduling." Our officers are often cited for their exceptional analytical capabilities and their ability to communicate this knowledge. I doubt we could retain this level of expertise if you and your students weren't continually encouraging us to share our ideas with you and challenging us to stay current. Thank you.

Sincerely

ANTHONY WAISANEN, Lt Col, USAF  
Chief, Resources Management  
Studies and Analysis Flight

CC:  
AFOSR (Dr Neal Glassman)



UNITED STATES TRANSPORTATION COMMAND

508 SCOTT DR

SCOTT AIR FORCE BASE IL 62225-6357

19 Jun 95

Professor Ervin Y. Rodin  
Director, Center for Optimization and Semantic Control  
Washington University  
One Brookings Drive  
St Louis MO 63130-4899

Dear Professor Rodin

We appreciate your efforts in creating a cooperative program between the Center for Optimization and Semantic Control and this command. In May 1994, you proposed such a program to our prior Commander in Chief, General Ronald R. Fogleman (currently Chief of Staff of the Air Force), who enthusiastically endorsed the idea.

We are pleased to learn that your program, consisting of voluntary summer student internships, is currently in place with four of your students working in our Directorate of Operations and Logistics. Since your research center specializes in applying artificial intelligence techniques to large transportation related problems, their internship should better prepare them to choose academic research topics with more practical applications. We will do our best to ensure their work experience is relevant and rewarding.

We commend your desire to ensure your students concentrate on problems of interest to the Defense Transportation System, and look forward to the mutual benefits this program will bring.

Sincerely

KENNETH R. WYKLE  
Lieutenant General, U.S. Army  
Deputy Commander in Chief

C O R A M H E A L T H C A R E

1842 Lackland Hill Parkway

St. Louis, Missouri 63146

Telephone 314.994.0100 / 800.992.2972

Faximile 314.994.0071

June 13, 1995

Air Force Office of Scientific Research  
Bolling AFB  
Washington, DC 20332-001

Gentleman:

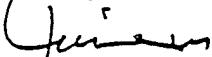
The purpose of this letter is to endorse and support the application of Professor Ervin Y. Rodin to your office, to renew his grant from you for his Center for Optimization and Semantic Control.

Several of my colleagues and I have been working for some time now with Professor Rodin, and with his colleagues and his students from the Center, on a variety of optimization problems. These problems are both medical and administrative in nature, and they are very important for the currently evolving new ways for the delivery of medical services efficiently. Examples of such problems are those for optimal dosage delivery, efficient scheduling of diagnostic tests, etc.

The fact that the essentially military type of research and development, with which Professor Rodin and his group are engaged, is so immediately utilizable for some of our most important problems, was a most pleasant surprise for us. Indeed, we are most grateful for the willingness of Professor Rodin and his group to share their knowledge and abilities with us so readily.

It is our considered opinion that such centers as his are national resources and deserve your support. Therefore, we commend and endorse his application to you wholeheartedly, and without reservations

Sincerely,



John D. Hirsch MD



UNITED STATES TRANSPORTATION COMMAND  
508 SCOTT DR  
SCOTT AIR FORCE BASE IL 62225-5357

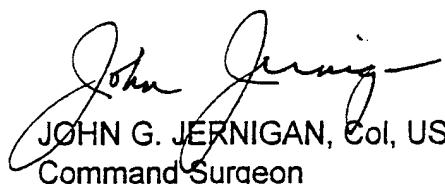
28 July 1995

MEMORANDUM FOR ACCREDITING AGENCIES

FROM: USTRANSCOM/SG  
508 SCOTT DRIVE  
SCOTT AFB IL 62225-5357

SUBJECT: Letter of Support for Dr. Ervin Rodin

1. This office has initiated a Cooperative Research and Development Agreement (CRDA) with the Washington University School of System Science and Mathematics, Center for Optimization and Semantic Control. Initial analysis accomplished under this agreement is targeted on the exploration of neural networks and other higher mathematics tools on outcome based outpatient clinical practice pattern recognition. Instrumental to success of this project, is the exploration, discovery, and feasibility of observed technologies demonstrating improved practice pattern recognition and improved clinical outcomes.
2. The U.S. Air Force invests significant revenues in the treatment of outpatient maladies. Current clinical practice patterns associated with the care of outpatient conditions include the potential for negative or non-value added outcomes. This research holds the potential to significantly reduce resource consumption and improve quality of patient care and clinical outcomes.
3. Dr. Rodin is to be singularly and personally commended for his devotion to service and research, both for this command and the United States Air Force.

  
JOHN G. JERNIGAN, Col, USAF, MC, CFS  
Command Surgeon  
United States Transportation Command

**MCDONNELL DOUGLAS**

*McDonnell Douglas Aerospace*

15 June 1995

United States Air Force  
Office of Scientific Research  
Washington, D.C.

Director of Scientific Research:

McDonnell Douglas Aerospace (MDA) currently is involved in a number of research programs with Washington University, St. Louis, Missouri, that involves advanced flight control technology for tomorrow's aircraft. These programs include:

- On-Line Neural Network based flight control systems that can adapt to damage conditions to fighter or transport aircraft and restore the controlled flight necessary to achieve safe recovery of passengers and crew.
- Self designing flight controller concepts that reduce development cost for new aircraft control systems by providing optimal response for all flight environments.

Such projects require a high level of expertise of academic staff and students to achieve success in these advanced flight programs. Our work with Washington University has demonstrated this expertise on both theoretical and practical levels for application to our aircraft products.

Based on our experience with Dr. Ervin Rodin and his staff, we fully expect to transition these flight control concepts to future flight test demonstration programs, and highly recommend AFOSR support to Washington University to achieve continuing advancements in flight control technology.

Sincerely,



James M. Urnes, Sr.  
Manager, Engineering  
New Aircraft and Missile Products  
MC 106 7075  
(314) 234-3775

kb/JU-6/14/95-016

United Van Lines, Inc.  
One United Drive  
Fenton, Missouri 63026  
(314) 326-3100



June 5, 1995

Office Of Scientific Research  
Bolling AFB, D.C. 20332

TO WHOM IT MAY CONCERN:

It is a pleasure for me to recommend continuation of the Air Force's contractual collaboration and professional relationship with The Center for Optimization and Semantic Control in the Department of Systems Science and Mathematics at Washington University. I have been associated and affiliated with Professor Ervin Y. Rodin and these organizations since 1986.

At that time, I was a part of the CINCMAC Analysis Group at HQ MAC at Scott AFB. We had a limited number of analysts and an unlimited number of analytical problems needing solutions. We quickly discovered that the use of Washington University's resources allowed us an extremely cost-effective way to provide solutions to high priority problems we would never have devoted attention to in-house. We established a close collaborative relationship which produced resolution of aeromedical evacuation schemes and improvements and streamlining of the MASS model, to name just two projects.

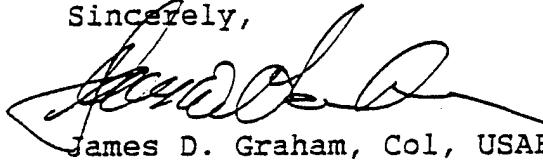
As you may remember, we were fortunate to acquire the Korbex Linear Programming (LP) System which we used quite successfully to solve enormous LPs, some with hundreds of thousands of variables and constraints. The Center's pioneering efforts in the use of artificial intelligence, expert systems, etc., has moved solution of these kinds of vexing transportation problems to an even higher success rate, particularly in producing integer answers earlier in the process -- always a problem with LPs.

Since my affiliation with United Van Lines in late 1991, I have continued to rely on Professor Rodin and the Center for highly effective solutions to United's more complex transportation

problems including siting of cross docks, optimization of our high-speed express service (Fastpath) and car carrier network and collection points. In all cases, the solutions produced were practical and doable.

In my opinion, your limited dollars are well-spent in maintaining this relationship as it is clearly a cost-effective way of advancing the Air Force's ability to systematically solve large complex transportation problems.

Sincerely,



James D. Graham, Col, USAF (Ret)  
Assistant to The Executive Vice  
President  
Director, Government Transportation  
Director, Market Research and  
Analysis



## Electronics & Space Corp.

8100 W. Florissant Ave.  
St. Louis, MO 63136

June 7, 1995

AFOSR/NM  
110 Duncan Avenue, Suite B115  
Bolling AFB, DC 20332-001

Dear Sir:

Electronics & Space Corp. (E&S), a defense contractor has, for the past six years, had an on going co-operative research program with the Center for Optimization and Semantic Control, Washington University under the leadership of Professors Rodin and Amin. The reason for a continued, on going relationship is that we, as a corporation, believe that the technology that they are pursuing a) is unique, b) offers cost effective solutions to many complex, defense related projects, and c) has also commercial potential. We have been pleased with their work both at an academic level and the very programmatic working relationship they have fostered with us.

However, our sponsorship alone is not sufficient to maintain this center. The University indicates that the on going sponsorship of the AFOSR is critical to the maintenance of this center. It is for this reason that Professor Rodin asked for this testimony. We have no hesitation in giving this endorsement to the quality of the work and the caliber of the professors and research students. In our opinion, their work is critical and provides benefit to the DoD and its contractors and potential benefit to commercial fields.

Should you wish for further details on any aspect of this letter, please don't hesitate to contact either of the below signees at E&S Corp.



Al Garcia  
Engineering Manager

Yours Sincerely,



John Wootton  
Director, Technology

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